

STRESS CORROSION CRACKING (SCC) OF LOW CARBON STEEL IN SELECTED ENVIRONMENTS

S. E. Ede, B.A. Okorie, and A.O. Agbo

Department of Metallurgical and Materials Engineering,
Enugu State University of Science and Technology.
sundayejioforede@yahoo.com

ABSTRACT

This study has investigated the effect of various values of tensile stress on low carbon steel in different environments ($1M\text{H}_2\text{SO}_4$, $1M\text{HCl}$, $1M\text{NaOH}$ and H_2O) where most conventional mild steels are normally exposed to while in service. The mild steel samples were pre-weighed and tensed in each of the environments with different stress values of 126.8N/m^2 , 169.1N/m^2 , 211.4N/m^2 and 253.6N/m^2 while the control sample was not tensed to any load. They were allowed to stand for 360 hours, with a set of samples from each environment withdrawn at intervals of 72 hours for corrosion characterization. The results obtained from all the environments studied showed that corrosion rate increased as values of stress increased. The sulphuric acid (H_2SO_4) environment recorded the highest corrosion rate followed by hydrochloric acid (HCl) environment, while sodium hydroxide (NaOH) and water (H_2O) environments recorded the lowest values of corrosion rates at both low and high applied tensile stress levels. Applied tensile stress and corrosive environment were discovered to be the primary cause of stress corrosion cracking in mild steel but the full mechanism is not well understood as the same applied stress could not induce corrosion in (NaOH) and water (H_2O) environments.

Keywords: Stress Corrosion Cracking (SCC) Corrosion, Acid, Applied Tensile Stress (ATS), Environment

1.0 INTRODUCTION

Stress corrosion cracking is cracking due to a process involving conjoint corrosion and straining of metal due to residual or applied stress. It is also thus the cracking induced from the combined influence of tensile stress and a corrosive environment. The impact of SCC on a material usually falls between dry cracking and the fatigue threshold of that material. The required tensile stress may be in the form of directly applied stresses or in the form of residual stress. (Straeche R.W 1977).

SCC is an insidious form of corrosion; it produces a marked loss of mechanical strength with little metal loss. The damage is not obvious to casual inspection and the stress corrosion cracks can trigger mechanical fracture fast, with catastrophic failure of component and structure (Gangloff R.P. 1984)

Several major disasters have involved stress corrosion cracking, including the rupture of high-pressure gas transmission pipes, the explosion of boilers, and the destruction of power stations and oil refineries. The occurrence of SCC depends on the

simultaneous existence of three conditions; (i) a susceptible material (ii) an environment that causes SCC for that material and (iii) sufficient tensile stress to induce SCC (Foroulls. Z. A 1977) There is no general rule which applies to one particular material or one specific environment since the same material may show quite different modes of fracture in different environments. However, most metals will exhibit SCC when stressed in specific environments while some do not. The important variables that determine length of time before failure are level of stress, environment, temperature, metal composition and metal structure (Moore J.J 1981). Engineers strive to use materials more efficiently by increasing the working load in different environment. The quest to identify the mechanisms of SCC has led to the discovery of different theories such as (i) Active path dissolution (ii) Hydrogen embrittlement and (iii) Induced-film cleavage, as accelerating factors responsible for SCC in all the environments that propagate stress corrosion cracking (SCC). (Bernstein I.M & Thompson .A.W. 1980).

Active path dissolution involves acceleration along a path of higher than normal corrosion susceptibility, with the bulk of the material typically being passive. The most common active path is the grain boundary, where segregation of impurity elements can make it marginally more difficult for passivation to occur. The effect of the applied stress is probably mainly to open up the cracks, thereby allowing easier diffusion of corrosion products away from the crack tip and allowing the crack tip to corrode more (Newman. R.C. and Procter .R.P.M. 1990). For the theory of hydrogen embrittlement; it must be noted that hydrogen dissolves in all metals to a moderate extent. It is a very small atom, and fits in between the metal atoms in the crystal lattice of the metal. Consequently, it can diffuse much more rapidly than larger atoms. For example, the diffusion coefficient of hydrogen in ferritic steel at room temperature is similar to the diffusion coefficient of salt in water. Hydrogen tends to be attracted to regions of high triaxial tensile stress where the metal structure is dilated. Thus, it is drawn to the region ahead of cracks or notches that are under stress. The dissolved hydrogen then assists in the fracture of the metal, possibly by making cleavage easier or possibly by assisting in the development of intense local plastic deformation. (Straechle 1977) These effects lead to embrittlement of the metals; cracking may be either intergranular or transgranular. Crack growth rates are typically relatively rapid, up to 1mm/s in the most extreme cases. (Parkins R. V. 2002)

2.0 MATERIALS AND METHODS

Experiments undertaken involved the study of stress corrosion cracking (SCC) of mild steel whose chemical composition and some mechanical properties are as shown in Table 1 below

Table1: Chemical compositions of the specimen

Heat No	620577
C	0.26
Mn	0.77
Si	0.26
S	0.013
P	0.021
Yield Strength (MNm ⁻²)	410
Ultimate Tensile (MNm ⁻²)	607
% Elongation	24

A mild steel rod of 16mm diameter and 130mm length was machined and holes were drilled at both ends for suspension during the experiments. Machining and drilling were done using a lathe machine and were checked for dimensional accuracy with vernier caliper and micrometer screw gauge.

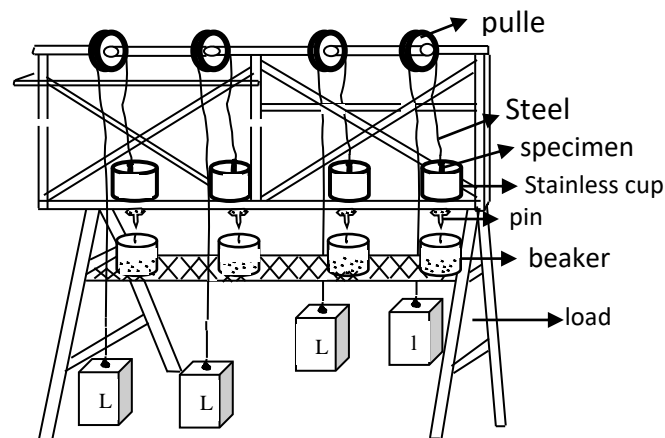


Fig 1: Facility for study of SCC

Figure 2 is the facility for stress corrosion cracking (SCC) study. It can be used for simultaneous suspension of steel specimens in four different environments under study, with the specimens subjected to known stress values. Initial weights of the machined steel specimens were taken with the aid of an electronic weighing scale. Then, the first set of four steel specimens were each fixed in the four stainless steel cups and hooked at the bottom with stainless pins through holes drilled at the lower ends of the specimens as shown in Figure 1. At the upper part of the specimens, steel springs were each passed and hooked through the hanging pulleys and finally tensed to choice loads as shown. 1mole

solutions of H_2SO_4 , HCl , $NaOH$ and distilled water (H_2O) were poured into each of the four stainless steel cups. The specimens under stress were held in the various media for a total of 360 hours, with weight loss measurements taken at interval of 72hours (three days).

For the weight loss measurements, the set-up was dismantled and the specimens removed, washed, dried, weighed and set up again for the same procedure. Stress values of $126.8N/m^2$, $169.1N/m^2$, $211.4N/m^2$ and $253.6N/m^2$ were used in the experiment,

while control specimens in each set of environments were not tensed to any load.

3.0 EXPERIMENTAL RESULTS AND DISCUSSION

Experimental results obtained in the course of these tests are presented on Table: 2. They include weight loss, corrosion rates, environments, and stress levels used after three days intervals for fifteen days. The data are presented in graphical form in Figures1-7

Table 2: Experimental data

Environment: 1MH₂SO₄, Applied Tensile Stress:126.8N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	8.8	36.58
144	10.2	21.20
216	10.6	14.69
288	11.0	11.43
360	9.8	8.14
Environment: 1M H₂SO₄, Applied Tensile Stress: 169.1N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	9.4	39.08
144	10.0	20.78
216	10.8	14.96
288	11.4	11.84
360	11.0	9.14
Environment: 1M H₂SO₄, Applied Tensile Stress: 211.4N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	10.0	41.57
144	10.8	22.45
216	11.0	15.24
288	11.6	12.05
360	11.8	10.00
Environment: 1M H₂SO₄, Applied Tensile Stress: 253.6N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	10.2	42.40
144	11.2	23.28

216	11.8	16.35
288	11.6	12.05
360	11.4	9.47
Environment: 1M H₂SO₄, Applied Tensile Stress: Nil		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	7.6	31.59
144	9.0	18.70
216	9.4	13.27
288	8.8	9.14
360	8.6	7.5
Environment: 1M HCl, Applied Tensile Stress: Nil		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	3.4	14.13
144	3.0	12.47
216	3.8	5.26
288	3.4	3.53
360	3.6	2.99
Environment: 1M HCl, Applied Tensile Stress: 126.8N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	4.2	17.46
144	4.8	10.00
216	5.2	7.20
288	4.8	4.98
360	4.6	3.82
Environment: 1M HCl, Applied Tensile Stress: 169.1N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate

		(MPY)
72	5.0	20.78
144	5.8	12.00
216	6.0	8.31
288	6.0	6.23
360	5.8	4.82
Environment: 1M HCl, Applied Tensile Stress: 211.4N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	5.0	20.78
144	5.8	12.00
216	6.0	8.31
288	6.0	6.23
360	5.8	4.82
Environment: 1M HCl, Applied Tensile Stress: 253.6N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	5.6	23.28
144	6.2	12.88
216	6.0	8.31
288	6.4	6.65
360	6.8	5.65
Environment: 1M NaOH, Applied Tensile Stress: 253.6N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	0.10	0.70
144	0.00	0.00
216	0.10	0.20
288	0.00	0.00
360	0.00	0.00
Environment: H₂O, Applied Tensile Stress: 253.6N/m²		
Time (Hours)	Weight loss (g)	Corrosion rate (MPY)
72	0.20	1.40
144	0.10	0.30
216	0.10	0.20
288	0.00	0.00
360	0.10	0.10

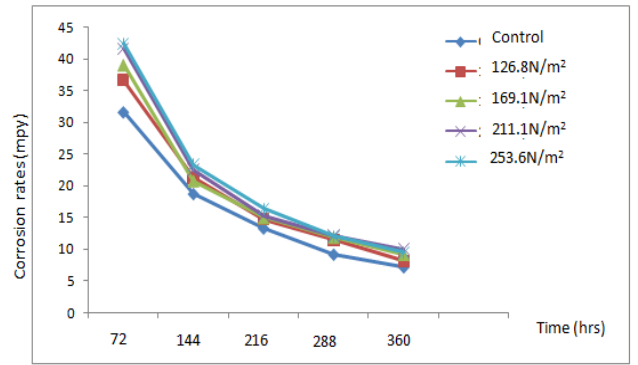


Fig 2 Corrosion rate against time for specimens subjected to various stress 1MH₂SO₄ environments

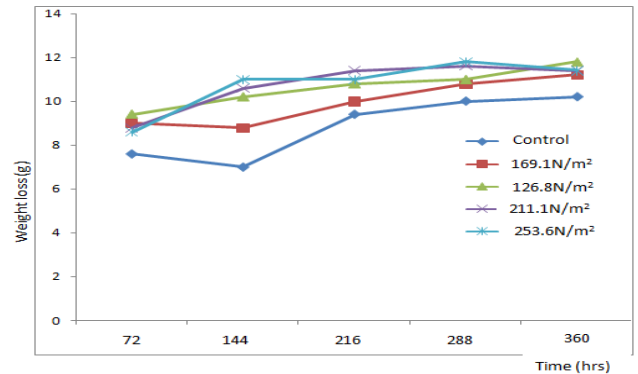


Fig3 Weight loss against time for specimens subjected to various stresses in 1MH₂SO₄ environments

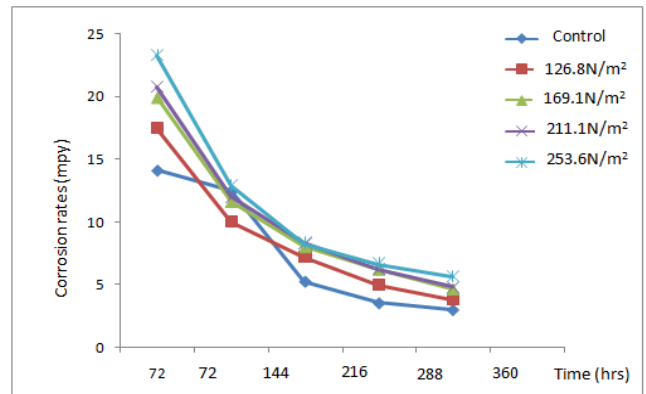


Fig4: Corrosion rate against time for specimens subjected to various stresses in (1MHCl) environments

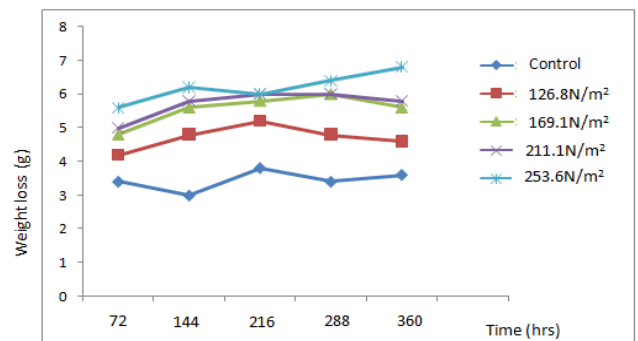


Fig5: Weight loss against time for specimens subjected to various stresses in 1MHCl environments

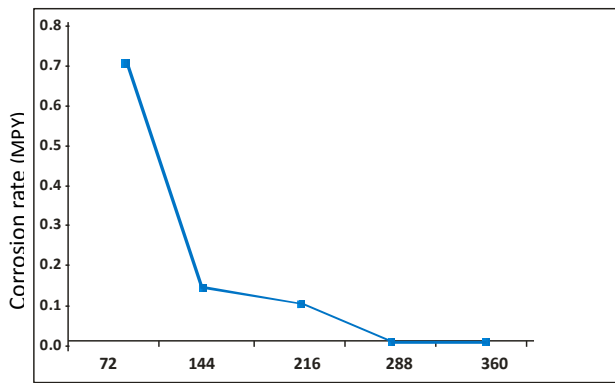


Fig6: Corrosion rate against time in 1MNaOH solution for specimen subjected to 253.6N/m²

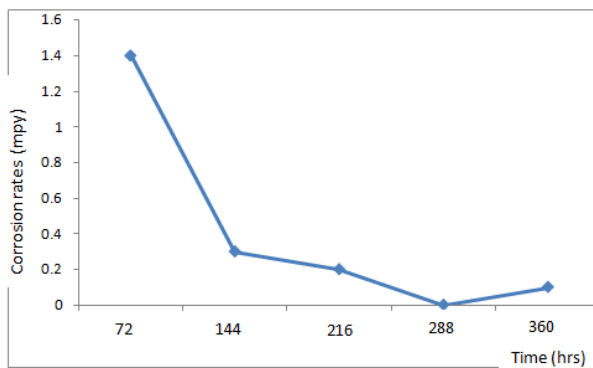


Fig7: Corrosion rates against time in neutral water environment for specimen subjected to 253.6N/m²

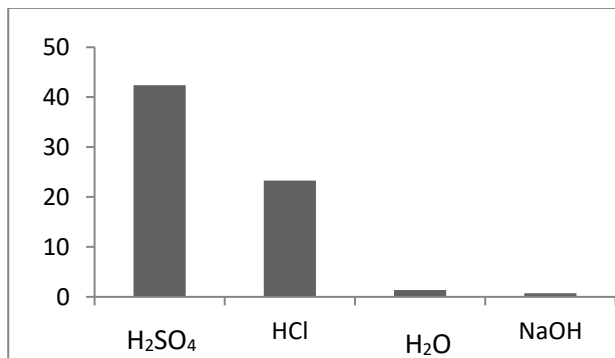


Fig 8: Column chart showing the values of corrosion rates in the four environments studied at a maximum stress of 253.6N/m²

Figure 2 is a plot of corrosion rate versus time (hrs) for the specimen subjected to various stress levels in sulphuric acid (H₂SO₄) environment. The corrosion rates had been calculated from the weight loss data. The graphs show very high initial corrosion rates for each applied stress level. The corrosion rates decreased rapidly with time. The rate of decrease of corrosion rate was very high in the first three days of the tests and then slowed down subsequently. This trend is observed for all the specimens including the control specimen which was

subjected to no stress at all. The graphs also showed clearly the effect of stress on corrosion rate in H₂SO₄ environment. The corrosion problem is exacerbated if a specimen is under stress, and it may be noted that the specimens subjected to higher stress level invariably suffer higher rates of corrosion. The reason for this is the development of an active path dissolution and hydrogen embrittlement as earlier discussed in the introduction.

Figure 3 is a graph of weight loss versus time in the sulphuric acid (H₂SO₄) environment just discussed. As expected, the graphs display higher weight losses for specimens subjected to higher stress levels.

Figure 4 is similar to Figure 2 but has been obtained for specimens subjected to various stresses in hydrochloric acid (HCl) environment. As with the H₂SO₄ environments, the trend of a very high initial corrosion rate which drops very rapidly in the first three days and then decreased less rapidly afterwards, may be observed. This graph also shows that in general, the specimens subjected to higher stress levels suffer higher corrosion rates but H₂SO₄ environment was observed to be more severe than HCl environments. Also, the results recorded for the control specimen show a rather slow rate of decrease of corrosion rate in the first three days, followed by a rapid decrease during the next three days. This behaviour is out of tune with the general trend observed and may be due to experimental error.

Figure 5 shows the weight loss versus time (days) for the specimen tested in the HCl environment. The data again shows that the specimen subjected to higher stress levels in the environment experience more severe losses in weight and therefore higher rates of corrosion. Furthermore, the reason why both environments showed a common trend in behaviour is that they are both acidic solutions. Metals, especially steels, tend to be in a passive region when free from air and moisture. When immersed in acidic solutions. The oxide films tend to dissolve completely leaving a bare metal surface which is then said to be in active state and under this state, metal dissolution in the

solution is highest. If the metal is under an applied tensile stress, it tends to open the crack tip the more, thereby allowing easier diffusion of corrosion products. The effect increases as the values of applied stress increase and the specimen with the highest tensile stress tends to corrode more, unlike the control specimen which is not subjected to any applied stress.

Figures 6 and 7 are corrosion rates against time for specimens subjected to $253.6N/m^2$ in NaOH and H₂O environments respectively. The results show that these environments do not cause stress corrosion cracking (SCC), since little corrosion rate was observed. It also shows that both environments are not aggressive media for steel. The results may be explained by the fact that when steel is exposed to a near-neutral solution like water, the solubility of the protective oxide will be much lower than in acid solution and the extent of dissolution will tend to be smaller. Secondly, if the near-neutral solution contains inhibiting anions like sodium hydroxide (NaOH), the dissolution of the oxide film may be suppressed and the oxide film stabilized to form a passivating oxide film which can effectively prevent the corrosion of the metal. Figure 8 represents the column chart of all the environments studied. It summarizes the results and also shows comparative results obtained in the four environments studied at the highest applied stress level.

4.0 CONCLUSION

This research work was centered on investigating stress corrosion cracking (SCC) of mild steel in some selected media of (NaOH, H₂O, H₂SO₄ and HCl) where the material (mild steel) may be exposed while in service. From the results obtained, the following deductions may be drawn.

1. At standard room temperature of 25°C, 1M H₂SO₄ and 1M HCl promote stress corrosion cracking (SCC) on mild steel.
2. Stress corrosion cracking and other forms of corrosion also thrive more in sulphuric acid environment than in hydrochloric acid environment.

3. The higher the stress level the more corrosion attacks the mild steel.
4. Little or no corrosion was observed in NaOH and H₂O within the time range of study at highest stress level.
5. Active path dissolution and hydrogen embrittlement were responsible for the high corrosion rates in sulphuric and hydrochloric acid environments.
6. NaOH solution was also found not to cause corrosion on mild steel.

REFERENCES

- Arup and Parkins R.N: Stress corrosion Research, NATO, 1979.
- Ashby M.F. and Jones D.R.H: Engineering Materials- Introduction to Properties and Applications, Pergamon, Vol 1 1980, Vol 2 1986.
- Bernstein, I.M and Thompson A.W.: Hydrogen Effect in Metals, AIME, 1980
- Moore J.J. Chemical Metallurgy (1st Edition). Butter Worth & Co. Ltd. 1981 Pages (305-307)
- Newman R.C and Procter R.P.M: Stress Corrosion cracking 1965-1990, British corrosion Journal Vol.25, no 4, 1990.
- Straechie R.W.: Stress corrosion cracking and Hydrogen Embrittlement of Iron Base Alloys NACE, 1977
- Foroulls Z. A; Environment Sensitive fracture of Engineering Materials AIME 1977.
- Gangloff R.P. Embrittlement, by the Localized crack Environment TMS-AIME 1984.
- Newman R.C. in Marcus P. and Qudar J.: corrosion Mechanism in Theory and Practice, Dekkar 1995.
- Shreir L.L. Jarman R.A. and Burstein C.T.: Corrosion, Vols I and II, Newness Worth, 1994.
- Parkins R.N.: Stress corrosion cracking. National Physical Laboratory (NPL) 2002.
- Shrein L.L. Electrochemical Principles of Corrosion- A guide for Engineers; Dept of Industry, 1982